Composite flavor-singlet scalar in twelve-flavor QCD

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(LatKMI Collaboration)

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Contents

Introduction

Discovery of "Higgs" particle @ LHC

$m_H \sim 126$ GeV

Still we have lots of things to understand, such as

- Property of "Higgs" particle

  elementary

- Mechanism of electroweak symmetry breaking

  $\langle H \rangle \neq 0$

- Gauge hierarchy problem

  fine tuning of m_H

Standard Model

Beyond Standard Model: SUSY, Little Higgs, Technicolor, $\cdots$

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Still we have lots of things to understand, such as

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  elementary　　　　　composite

- Mechanism of electroweak symmetry breaking

  $\langle H \rangle \neq 0$　　　　　VEV from dynamics

- Gauge hierarchy problem

  fine tuning of m_H　　　　　no fine tuning

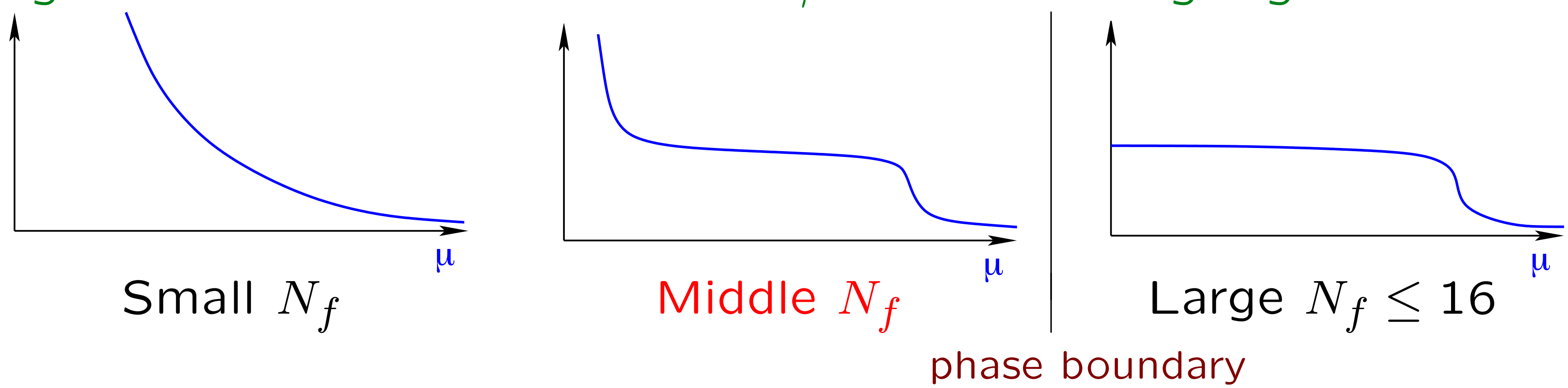
Standard Model　　　　　Technicolor: strongly coupled theory

Beyond Standard Model: SUSY, Little Higgs, Technicolor, $\cdots$

Walking technicolor

N_f massless fermions + SU(N_{TC}) gauge at $\mu_{\mathrm{TC}} = O(1)$ TeV

- Spontaneous chiral symmetry breaking
- Slow running (walking) coupling in wide scale range
- Large anomalous mass dimension $\gamma^* \sim 1$ in walking region



- Composite, light scalar state

$$\approx \text{Higgs} \rightarrow \text{explain } M_{\text{Higgs}}/v_{\text{EW}} \sim 0.5$$

Walking technicolor

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Question: Such a theory really exists?

Nonperturbative calculation is important.

$\rightarrow$ numerical calculation with lattice gauge theory

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Lattice studies for (approximate) conformal gauge theory:

'92 Iwasaki *et al.*, '92 Brown *et al.*, '97 Damgaard *et al.*,
'08 Appelquist *et al.*, and various other works

Purpose of our project

Search for candidate of walking technicolor

Systematic investigation of N_f dependence

SU(3) gauge theory with $N_f = 0, 4, 8, 12, 16$ fermions

Common setup for all N_f: Improved staggered action (HISQ/Tree)

Cheaper calculation cost + small lattice systematic error

'12 Bazakov *et al.*

Recent works of our group

- Basic physical quantities: m_π, F_π, m_ρ, $\langle\overline{\psi}\psi\rangle$
  $N_f = 12$: PRD86(2012)054506
  $N_f = 8$: PRD87(2013)094511 [Kei-ichi Nagai: 1F]
  $N_f = 8$ may be candidate of walking theory
- Flavor-singlet scalar in (approximate) conformal theory
  $N_f = 12$: arXiv:1305.6006; glueball [Enrico Rinaldi: 1F]
  $N_f = 8$ [Hiroshi Ohki: 1F]
- $N_f = 8$ S parameter [Yasumichi Aoki: 5F]

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Purpose of this talk

Search for candidate of walking technicolor

Why $N_f = 12$

- Investigated by many groups

  '08,'09 Appelquist *et al.*, '10 Deuzeman *et al.*, '10,'12 Hasenfratz,
  '11 Fodor *et al.*, '11 Appelquist *et al.*, '11 DeGrand, '11 Ogawa *et al.*,
  '12 Lin *et al.*, '12 Itou, '12 Jin and Mawhinney, and $\cdots$

In our work PRD86(2012)054506

consistent behavior with conformal phase

- Flavor-singlet scalar in conformal theory is not understood well.
  1. SU(2) Adjoint $N_f = 2$ glueball: '09 Del Debbio *et al.*
  2. SU(3) $N_f = 12$ meson: '12 Jin and Mawhinney

Purpouse of this work

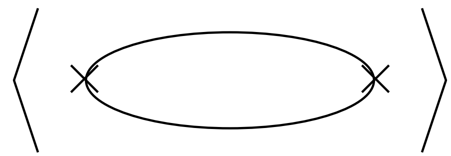
Understand properties of flavor-singlet scalar in $N_f = 12$

regarded as pilot study of more interesting $N_f = 8$ theory

Difficulty of flavor-singlet scalar meson

- Flavor non-singlet scalar meson $S_{NS}(t) = \sum_{\vec{x}} \overline{\psi}_a(\vec{x},t)\psi_b(\vec{x},t)\ (a \neq b)$

$$\langle 0|S_{NS}(t)S^{\dagger}_{NS}(0)|0\rangle \quad =$$



$$= -C(t)$$

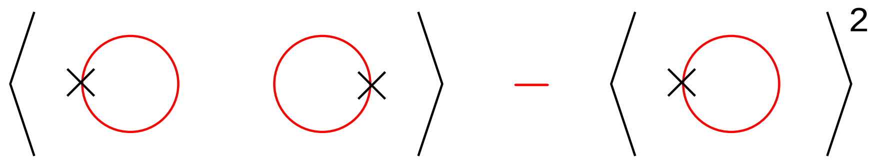
c.f. m_π, F_π from non-singlet pseudoscalar

$O(10)$ configurations $\times$ $O(1)$ $D^{-1}[U](x,y)$

- Flavor-singlet scalar meson $S(t) = \sum_{\vec{x}} \overline{\psi}_a(\vec{x},t)\psi_a(\vec{x},t)$

$$\langle 0|S(t)S^{\dagger}(0)|0\rangle \quad = -C(t) + 3D(t)\ \text{(disconnected)}$$

$$D(t) =$$



Much harder but essential for flavor-singlet

$O(10000)$ configurations $\times$ $O(100)$ $D^{-1}[U](x,x)$

Difficulty of flavor-singlet scalar meson

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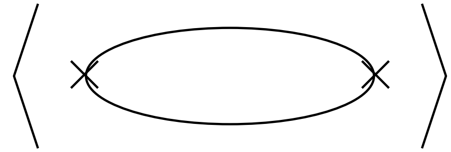
$\langle 0|S_{NS}(t)S^{\dagger}_{NS}(0)|0\rangle =$  $= -C(t)$

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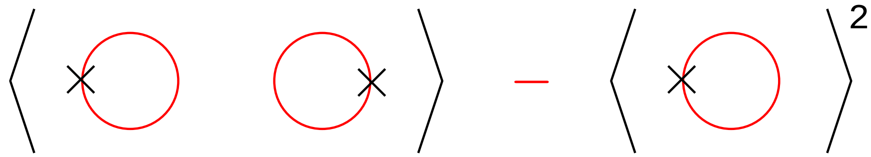
$D(t) =$ 

Much harder but essential for flavor-singlet

$O(10000)$ configurations $\times$ $O(10)$ $D^{-1}[U](x,x)$

using noise reduction method

'97 Venkataraman and Kilcup

Flavor-singlet scalar in $N_f = 12$ QCD

arXiv:1305.6006

Simulation parameters

- $\beta = 4$ HISQ/Tree action

  Consistent with conformal phase

  LatKMI; PRD86(2012)054506

- Huge number of configurations

  measuring every 2 tarj.

- Four m_fs on more than two volumes

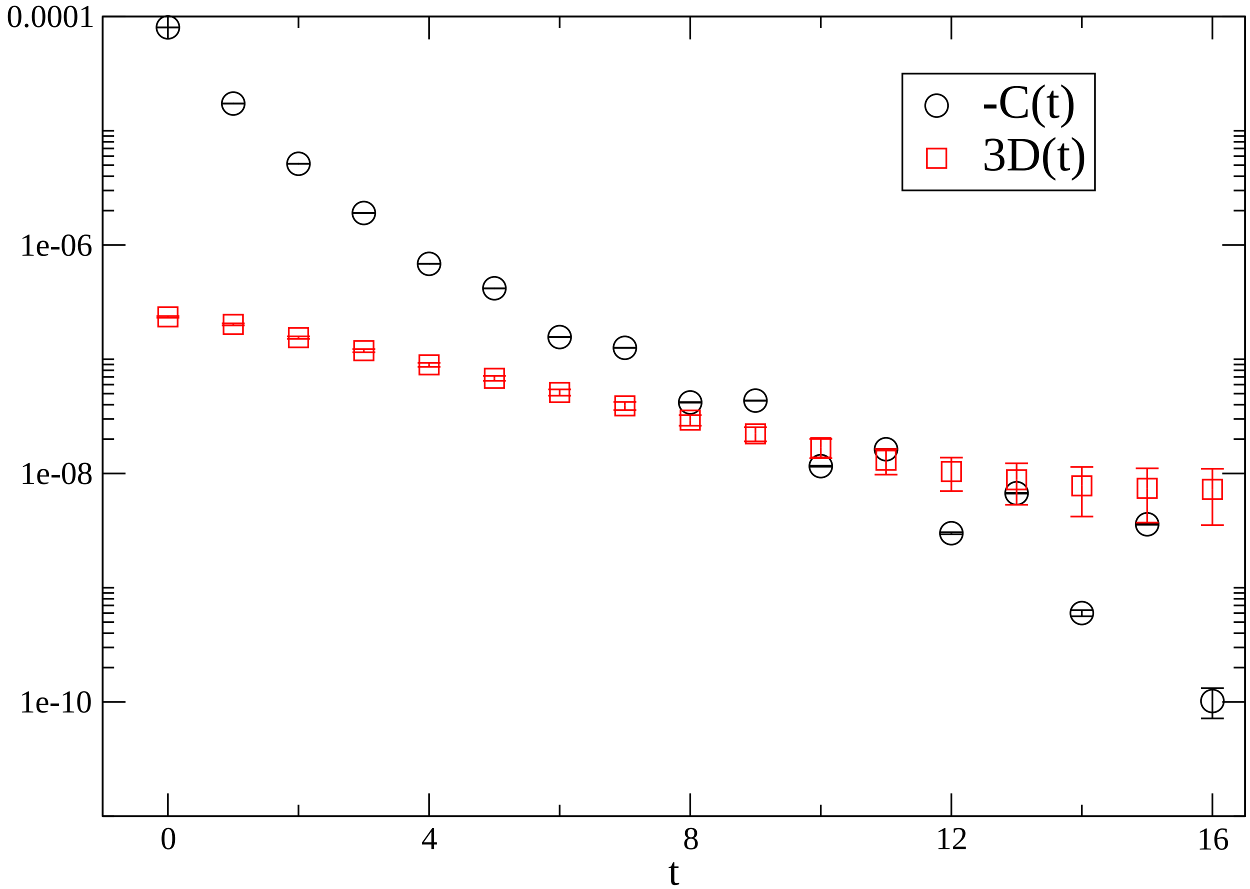
- Noise reduction method with $N_r = 64$

- Local meson operator of $(1 \otimes 1)$

L, T	m_f	confs
24,32	0.05	11000
	0.06	14000
	0.08	15000
	0.10	9000
30,40	0.05	10000
	0.06	15000
	0.08	15000
	0.10	4000
36,48	0.05	5000
	0.06	6000

Machines: φ at KMI, CX400 at Kyushu Univ.

Correlators in $N_f = 12$ ($m_f = 0.06, L = 24$ with $N_{\rm conf} = 14000$)

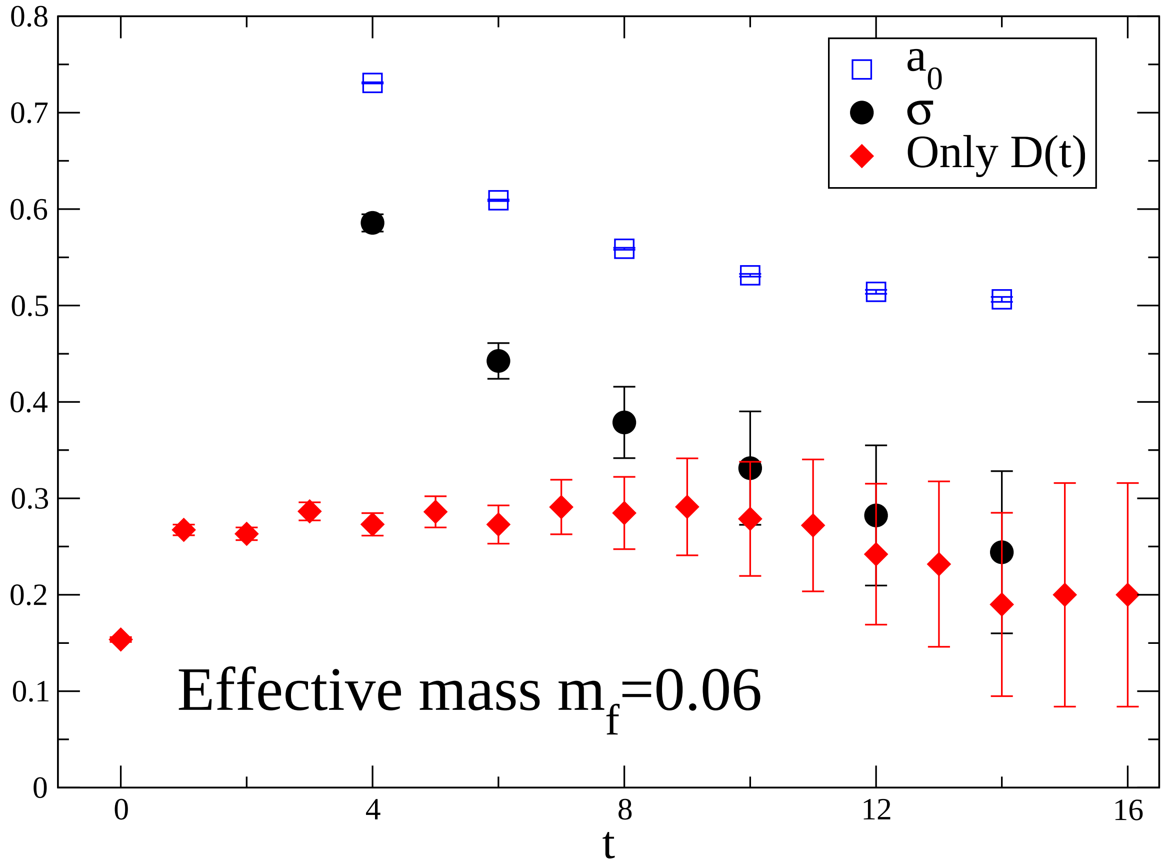


$-C(t)$ oscillates, but $D(t)$ does not

cancellation: species-singlet and non-singlet $\pi_{\rm SC}$ in $D(t)$

thanks to small taste symmetry breaking; PRD86(2012)054506

Effective mass in $N_f = 12$ ($m_f = 0.06, L = 24$ with $N_{\rm conf} = 14000$)



Non-singlet scalar

a_0: $-C_+(t)$

Singlet scalar

σ: $3D_+(t) - C_+(t)$

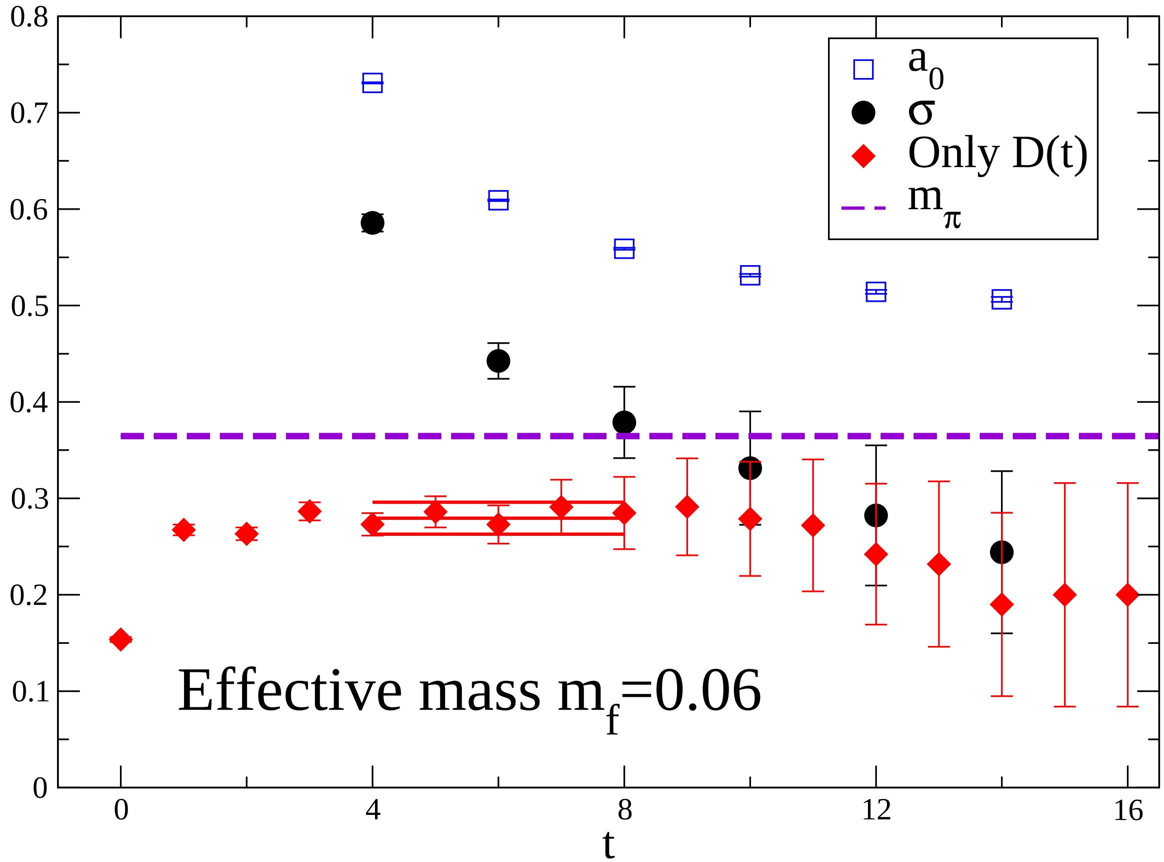
σ: $D(t)$ i.e. $m_\sigma < m_{a_0}$

Consistent m_σ with smaller error

$$X_+(t) = 2X(t) + X(t+1) + X(t-1)$$

Good signal of m_σ from $D(t)$

Effective mass in $N_f = 12$ $(m_f = 0.06, L = 24$ with $N_{\rm conf} = 14000)$



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Singlet scalar

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σ: $D(t)$ i.e. $m_\sigma < m_{a_0}$

Consistent m_σ

with smaller error

$m_\sigma < m_\pi$ at $m_f = 0.06$

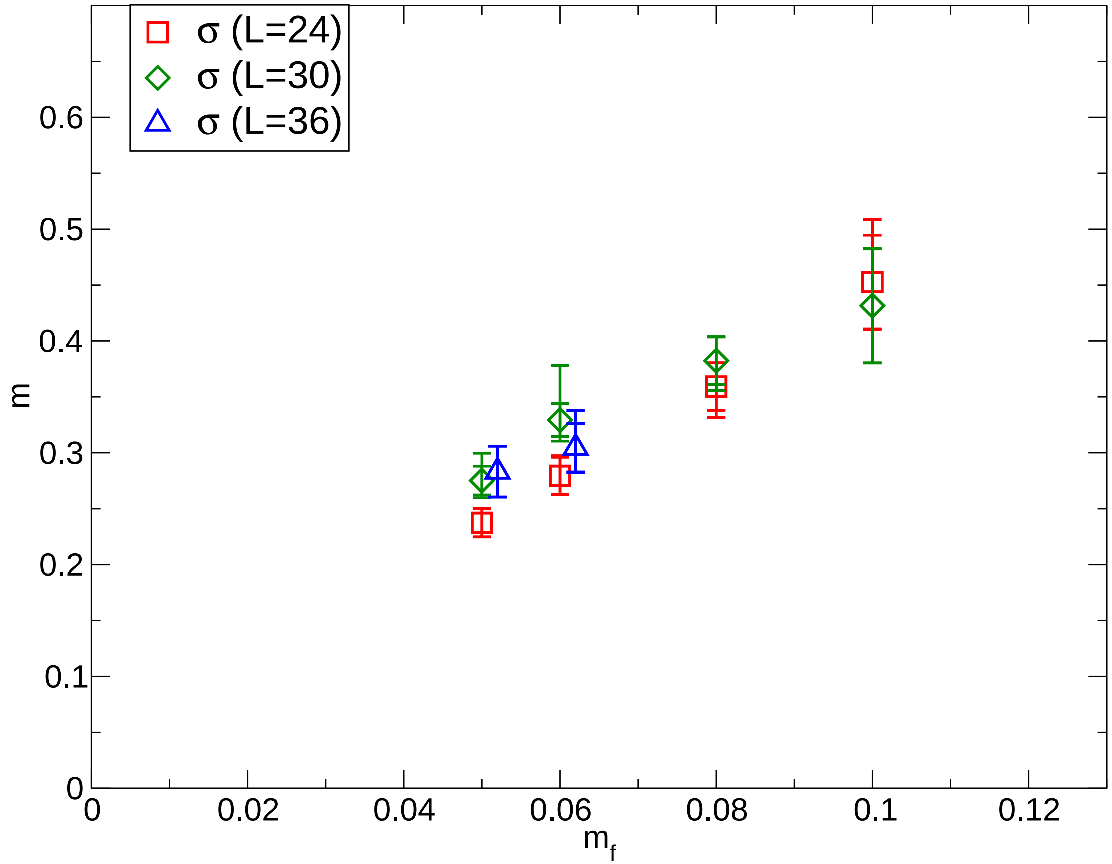
$$X_+(t) = 2X(t) + X(t+1) + X(t-1)$$

Good signal of m_σ from $D(t)$

m_f dependence of m_σ in $N_f = 12$

arXiv:1305.6006

m_σ from fit of $D(t)$ with $t = 4$–8



Reasonable signals with almost 10% statistical error

Systematic error from fit range dependence of $D(t)$

Finite volume effect under control $\leftarrow$ 2 larger volumes agree

m_f dependence of m_σ in $N_f = 12$

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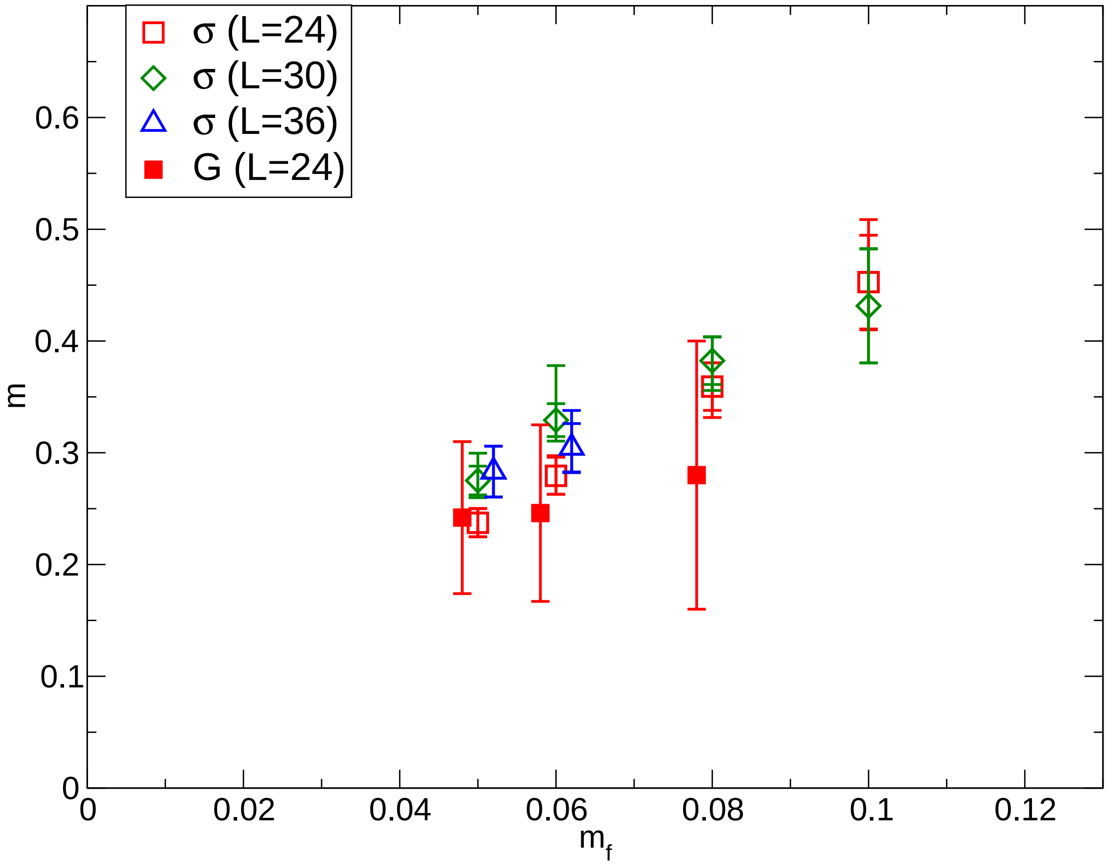
m_σ from fit of $D(t)$ with $t = 4$–8



Consistent mass from glueball operator calculation

[Enrico Rinaldi: 1F]

m_f dependence of m_σ in $N_f = 12$

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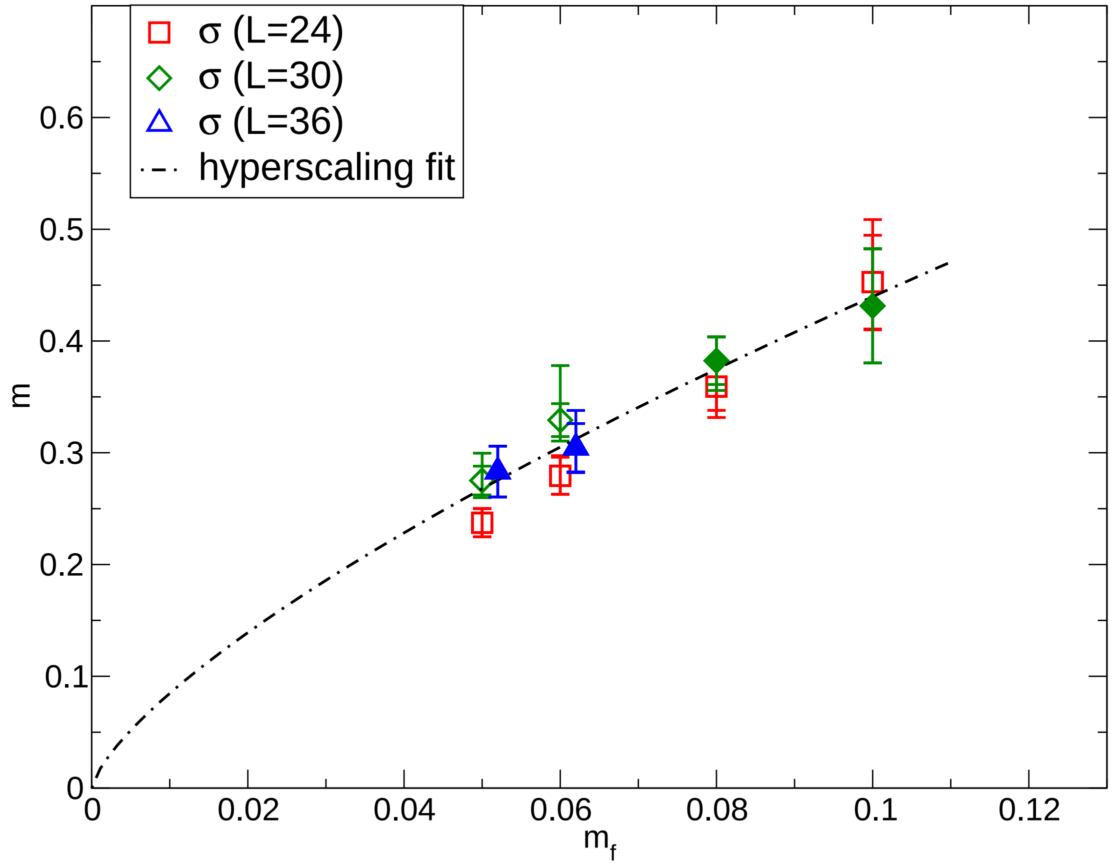

Hyperscaling test with fixed γ using larget volume at each m_f

$$m_\sigma = C m_f^{1/(1+\gamma)} \text{ with } \gamma = 0.414 \text{ from hyperscaling of } m_\pi$$

Consistent hyperscaling as m_π

m_f dependence of m_σ in $N_f = 12$

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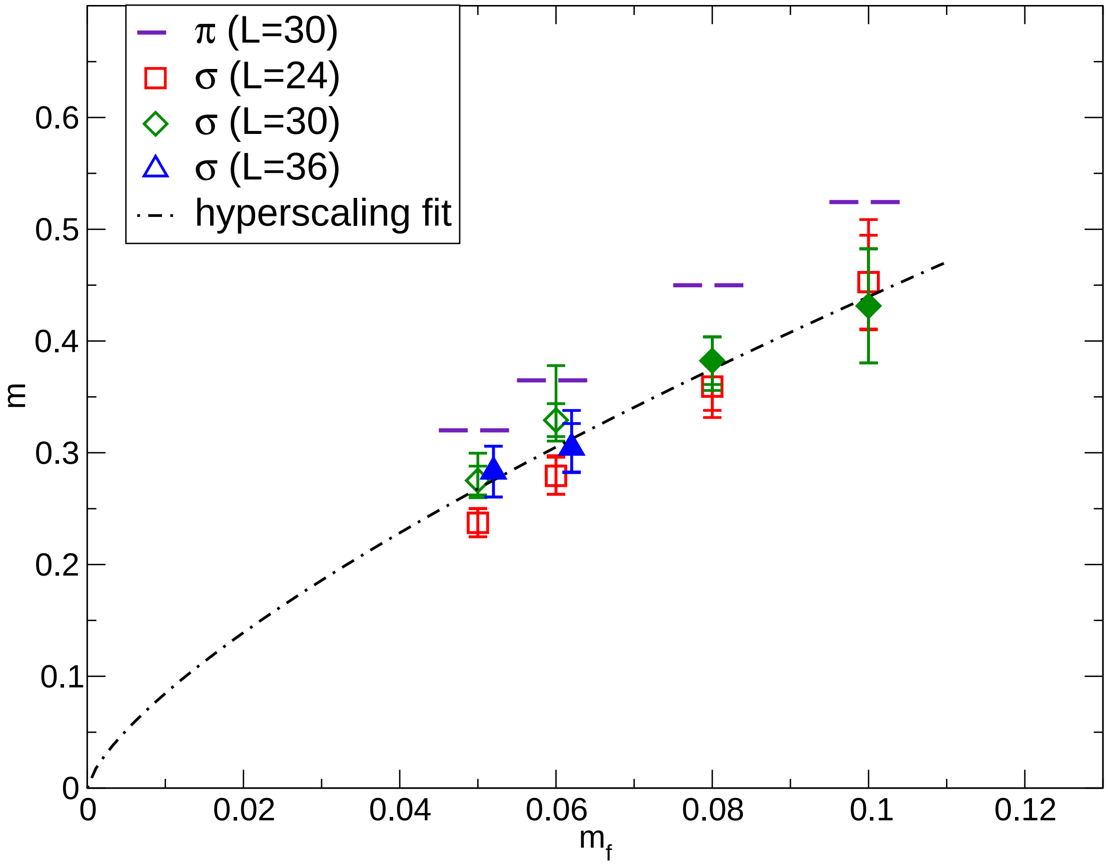


Lighter than π in all m_f

Much different from usual QCD

Conformal symmetry may make σ light

Summary

Flavor-singlet scalar is important in walking technicolor theory.

However, difficult due to huge noise in lattice simulation
$\Rightarrow$ Noise reduction method and Huge N_{conf} $O(10000)$

Results of $N_f = 12$ QCD (consistent with conformal phase)
- Consistent behavior with hyperscaling
- $m_\sigma < m_\pi$; much different from small N_f QCD
- Conformal symmetry may make σ light

Encouraging results for light σ in walking theory

Future perspectives

Candidate of walking theory: $N_f = 8$ QCD [Kei-ichi Nagai: 1F]

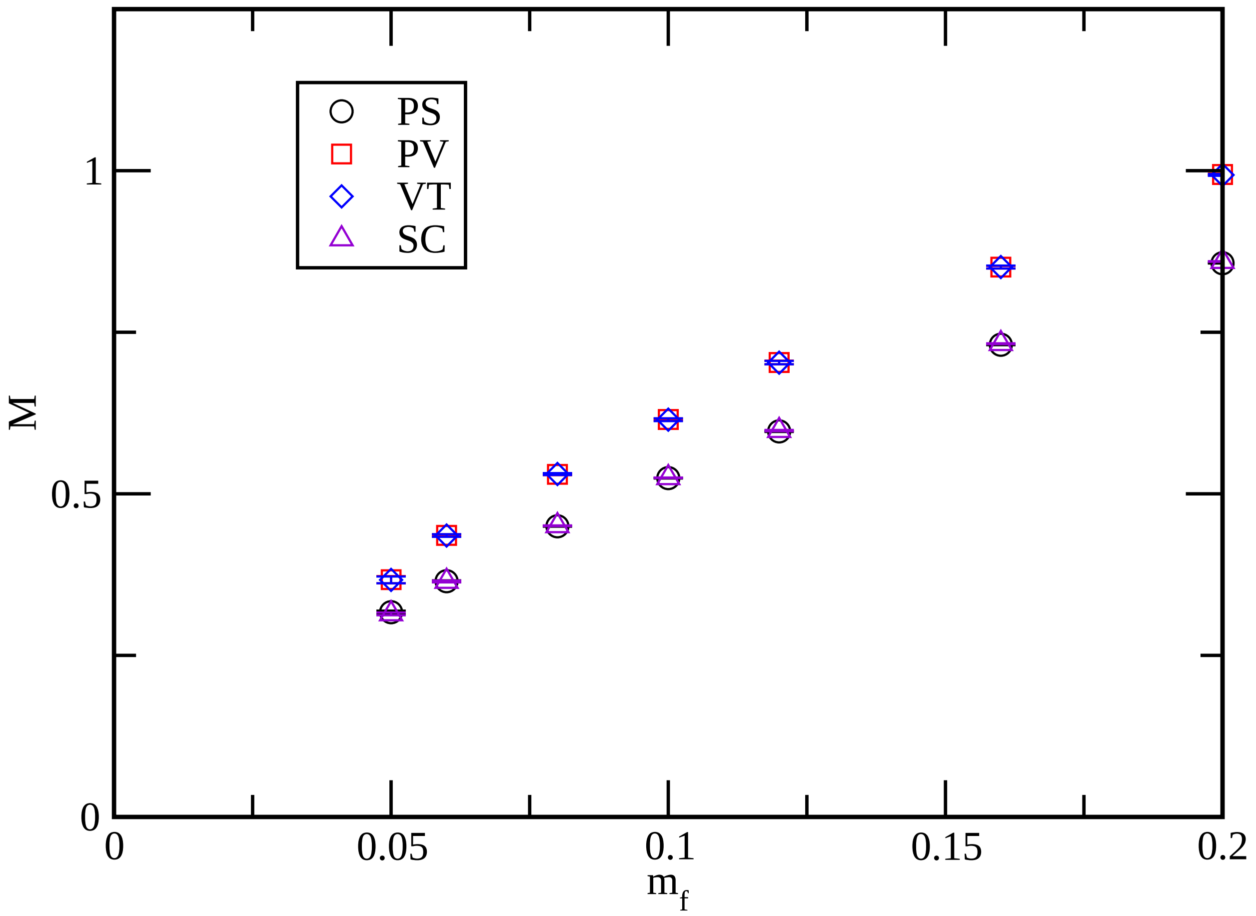
Important to study flavor-singlet scalar, if $m_\sigma \sim F_\pi$
Preliminary result of $N_f = 8$ QCD [Hiroshi Ohki: 1F]

Back up

$N_f = 12$ taste symmetry breaking effect

LatKMI; PRD86(2012)054506

0^-: PS, SC; 1^-: PV, VT



Small taste symmetry breaking in meson masses

States in $D(t)$

$A_H(t) = A_H \exp(-M_H t)$

Connected part

$$-C(t) = A_{a_0}(t) + (-1)^t A_{\pi_{\mathrm{SC}}}(t)$$

Connected + disconnected

$$N_f D(t) - C(t) = A_\sigma(t) + (-1)^t A_{\pi_{\overline{\mathrm{SC}}}}(t)$$

$$\xrightarrow{\text{taste symmetric limit}} \pi_{\overline{\mathrm{SC}}} = \pi_{\mathrm{SC}} = \pi_{\mathrm{PS}}$$

$\pi_{\overline{\mathrm{SC}}}$: Species-singlet but taste-non-singlet 0^-

η in PRD76:094504(2007)

disconnected part

$$N_f D(t) = A_\sigma(t) - A_{a_0}(t) + (-1)^t \left(A_{\pi_{\overline{\mathrm{SC}}}}(t) - A_{\pi_{\mathrm{SC}}}(t)\right)$$

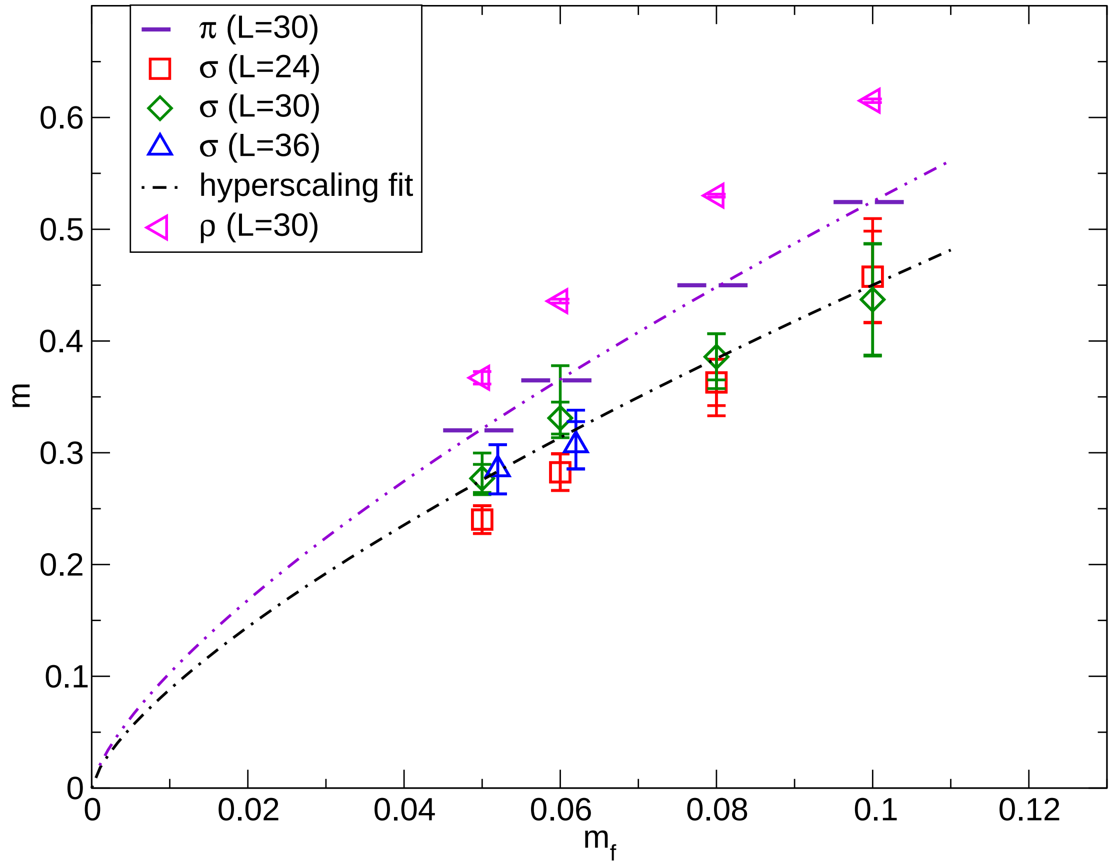
$$\xrightarrow{\text{taste symmetric limit}} A_\sigma(t) - A_{a_0}(t)$$

$\Rightarrow$ small oscillation in $D(t)$ if good taste symmetry

m_f dependence of m_σ in $N_f = 12$

arXiv:1305.6006

m_σ from fit of $D(t)$ with $t = 4$–8



Lighter than π in all m_f

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m_f dependence of m_σ/m_π

arXiv:1305.6006

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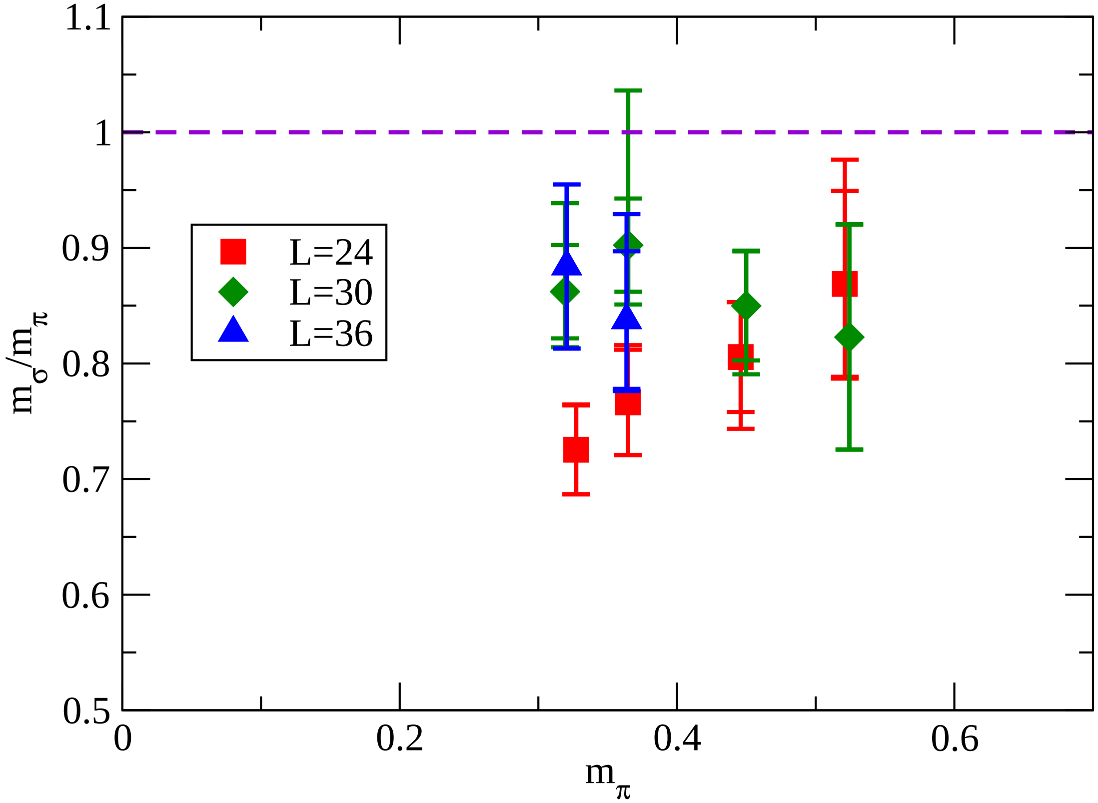

Discussion

Why flavor-singlet scalar calculation is possible?

- Nice noise reduction method
- Huge N_{conf}
- Small m_σ $\rightarrow$ slow exponential damp of correlator
- Small taste symmetry breaking $\leftarrow$ improved action, large N_f, etc.